6.3 ARCHITECTURAL COMPONENTS

6.3.2 INTERIOR PARTITIONS

6.3.2.1 INTERIOR PARTITION WALLS, HEAVY

Heavy partitions may be full or partial height and may be constructed of reinforced or unreinforced masonry. Older office buildings were often built with hollow clay tile partitions throughout much of the interior. These elements are found as infill along column lines or located away from the structural framing or walls. Although "nonstructural" in their intended function, masonry partitions often become "structural" in the sense that they affect the overall response of the building to earthquakes and thus require the expertise of a structural engineer to properly assess. Unless rigid partitions are located in a stiff building with very small inter-story drifts, they should be isolated from the structural system or be explicitly included in the lateral force design of the building.

TYPICAL CAUSES OF DAMAGE

- Heavy partitions are both acceleration and deformation sensitive and may fail either in-plane or out-of-plane if not properly detailed. Partial height partitions may fail unless they are laterally braced to the structure above or engineered to cantilever from below. Full height partitions may fail unless they are isolated from the building deformations and provided with out-of-plane restraint.
- Masonry may crack and spall, walls may collapse creating falling hazards and blocking corridors and exits with debris. Masonry debris may be particularly hazardous in stairwells and elevator shafts.
- Where partitions are used as lateral support for piping, electrical cabinets, storage shelves, or other nonstructural items, the failure of the partition wall may result in damage to these other components.

Where partitions are built tight against structural columns, there is a potential for the masonry wall to unintentionally create a “captive column” thereby changing the intended earthquake response of the building. A structural engineer is needed to evaluate the implications of such conditions.

Damage Examples

Figure 6.3.2.1-1 Damage along the top of a reinforced concrete masonry unit partition built flush with soffit of metal deck at an industrial facility in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.3.2.1-2 Damage to reinforced concrete masonry partition used to support fire protection cabinet and piping in the 2001 Peru Earthquake; loose stucco and masonry were removed prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.3.2.1-3 Damage to structural column ("captive column") due to restraint caused by partial height masonry wall in the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.3.2.1-4 View of stairway in the Banco Central Building, Managua, Nicaragua after the 1972 magnitude 6.2 Managua Earthquake. Most of the stairs were covered with debris that resulted from the failure of the hollow tile partitions surrounding the stairs (Photo courtesy of PEER Godden Collection, No. J94).

Figure 6.3.2.1-5 Damage to unreinforced brick partitions in patient rooms, and other mostly nonstructural damage, resulted in the evacuation of the Felix Bulnes Hospital in Santiago in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, University of Buffalo, SUNY).

Figure 6.3.2.1-6 An infill masonry wall collapsed onto the distilled water equipment spilling two 150 gallon containers; water leaked past the perimeter edge of the floor slab into the operating room suite below resulting in the closure of 3 of 6 the operating rooms. Replacement gypsum board partition seen in photo. Hospital built in 2005 in Los Angeles, Chile. Damage from the 2010 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

SEISMIC MITIGATION CONSIDERATIONS

- Heavy full height partitions need out-of-plane restraint with an in-plane slip joint. This can be provided with steel angles on either side attached to the structural slab above as shown. Steel angles may be continuous or intermittent; check code requirements. Note that special details may be required to meet fireproofing, sound proofing, weatherproofing or insulation requirements.
- Care must be used in detailing slip joints for a series of interconnected perpendicular walls since the out-of-plane restraints for one wall will prevent in-plane slip along the perpendicular wall; vertical isolation joints may be required. Similarly, special details are required where the soffit of the structure above has an irregular profile that would prevent slip such as the metal deck in Figure 6.3.2.1-1, or a sloping profile such as a ramp.

- If the partition will be used to provide lateral restraint for other nonstructural items, check that the wall and the lateral restraints at the top are adequate to resist the additional loading.
- Heavy partial height partitions are often used in exterior walls with glazing above or used as guardrails along exterior corridors. In buildings with structural frames, these walls should be self supporting and isolated from the structural framing at both ends. Failure to provide appropriate seismic isolation for these partial height walls has resulted in thousands of structural "captive column" failures in past earthquakes.

Mitigation Examples

Figure 6.3.2.1-7 Detail of isolation joint to prevent creation of "captive column" condition (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.3.2.1-8 Full-height concrete masonry unit walls detailed with steel clip angles (3 angles visible in photo). Configuration shown includes perpendicular walls, sloping ramp above, and column with column capital. Although wall detailed with sealant joints along edges of column and column capital, it is not clear that the concrete frame can move independently of these CMU walls (Photo courtesy of Cynthia Perry, BFP Engineers).

Mitigation Details

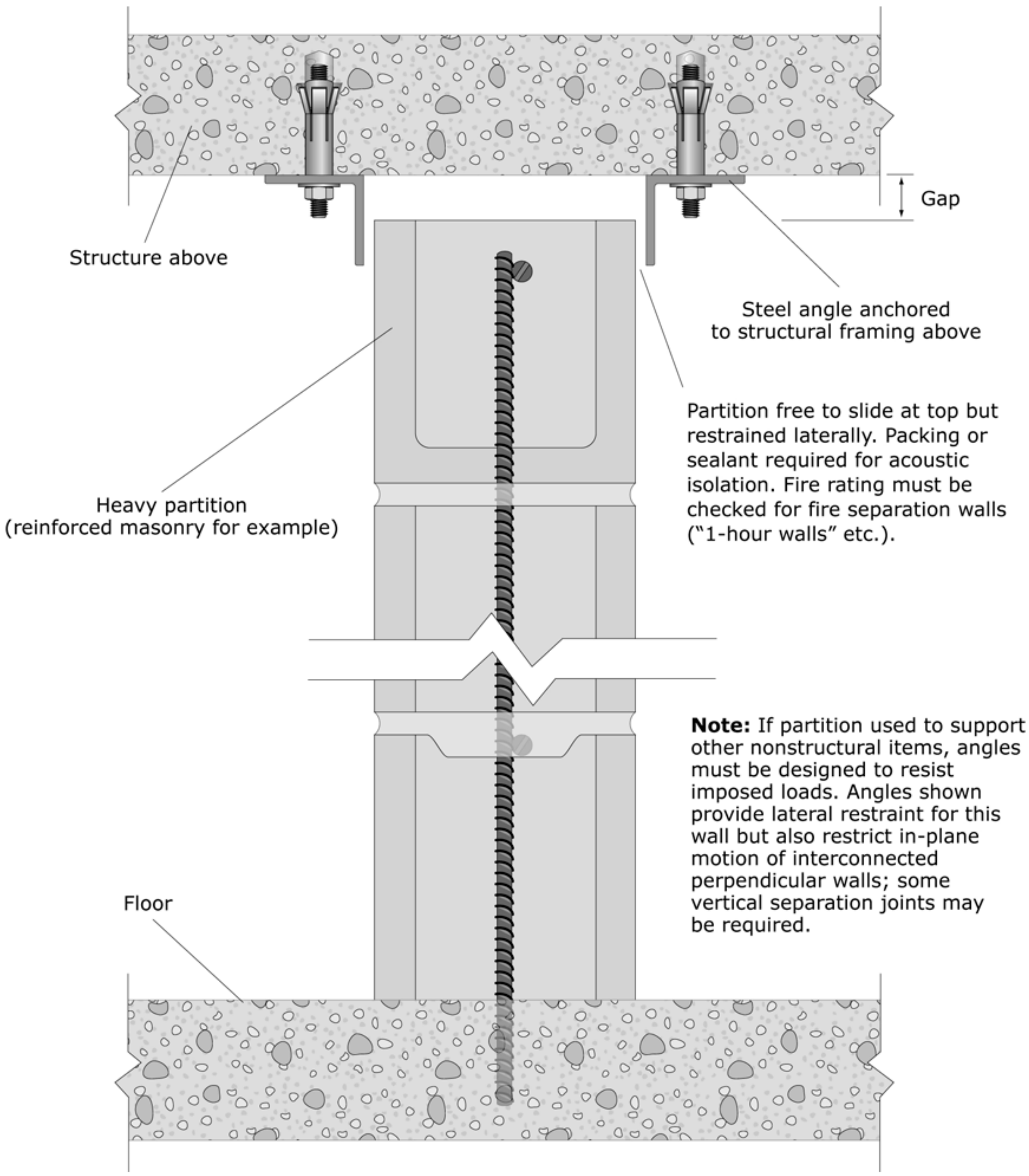


Figure 6.3.2.1-9 Full height heavy partition (ER).

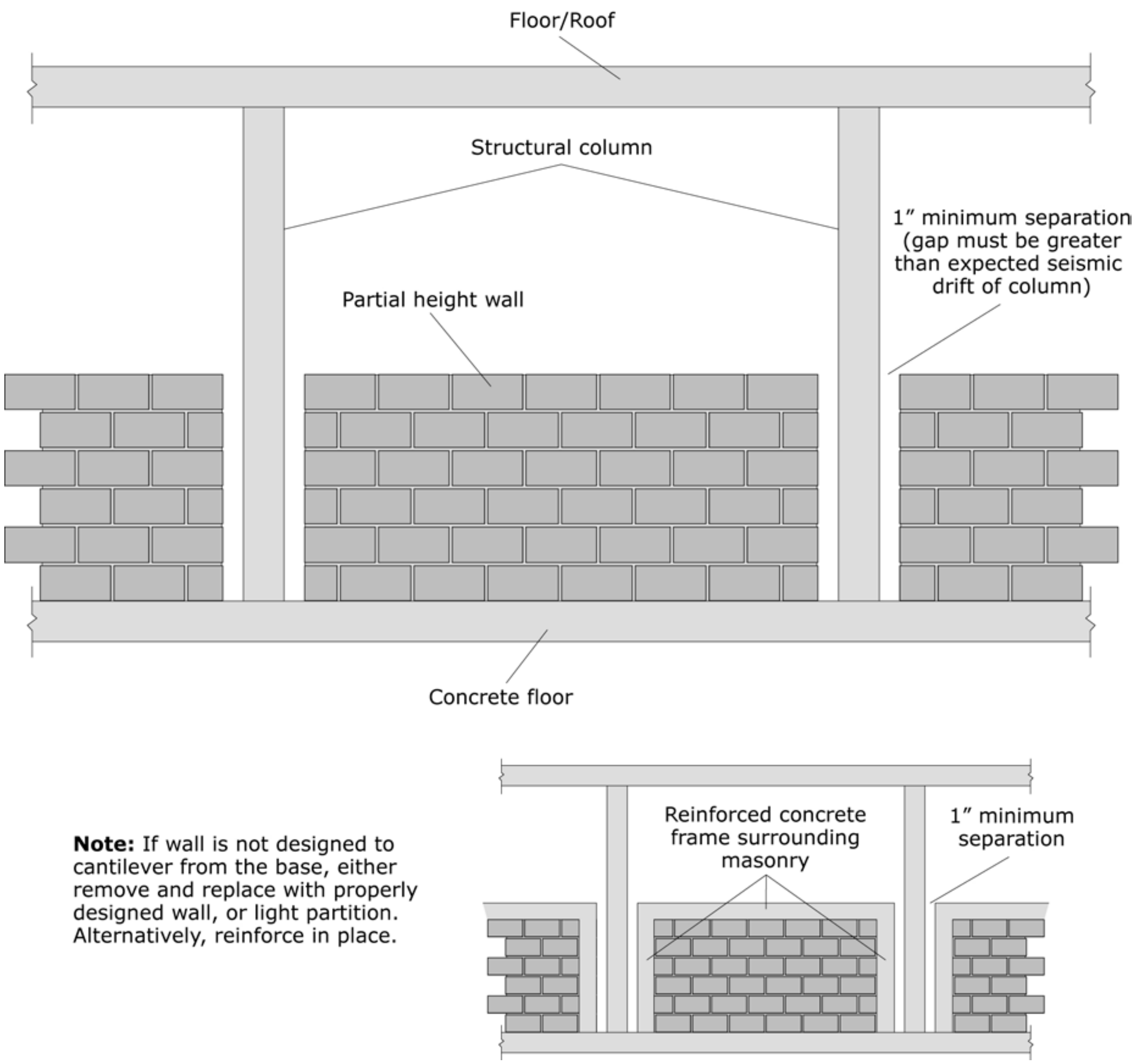


Figure 6.3.2.1-10 Partial height heavy partition (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.2 INTERIOR PARTITIONS

6.3.2.2 INTERIOR PARTITION WALLS, LIGHT

Light partitions may be full height (extending from floor-to-floor) or partial height (extending to the ceiling but not to the structural framing above) and are typically built using wood or metal studs with gypsum board or lath and plaster finish.

TYPICAL CAUSES OF DAMAGE

- Light partitions may be damaged as a result of in-plane or out-of-plane loading if not properly detailed. Full height partitions in flexible structures may fail unless they are isolated from the building deformations. Typical damage consists of cracked or spalled finishes, deformed partition faming, and failed connections. Partial height partitions may damage ceiling framing to which they are attached or can fall out-of-plane unless they are laterally braced to the structure above.
- Partition failures may create failing hazards, block corridors, and endanger occupants attempting to exit from damaged buildings.
- Where partitions are used as lateral support for electrical panels, storage shelves, or other nonstructural items, the failure of the partition wall may result in damage to these other components. Unless the partitions are properly designed, heavy items anchored to a light wall could also precipitate failure of the partition wall.
- Metal stud partitions are often detailed on drawings with a slip track to allow relative movement between the vertical studs and gypsum sheathing (attached to the lower floor) and the top track (attached to the slab above). Although these detail drawings typically state that full height gypboard should not be screwed to the top track, it is quite common to find them screwed together in the field rendering them the same as rigidly attached partitions. Gypsum board partitions (8 ft tall) that are rigidly attached to two adjacent floors typically are damaged with approximately 0.5 inch of interstory drift.

Damage Examples

Figure 6.3.2.2-1 Failure of inadequately braced partial height metal stud partitions in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).

Figure 6.3.2.2-2 Damage to wood stud wall spanning floor-to-floor in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).

SEISMIC MITIGATION CONSIDERATIONS

- For multistory and other engineered buildings, non-load bearing partitions should be isolated from the structural system in order to minimize costly partition damage. For these situations, full height partitions need out-of-plane restraint with an in-plane slip joint to isolate them from the building deformations. This is typically provided through special metal stud framing details. Note that special details may be required to meet fireproofing, sound proofing, weatherproofing, or insulation requirements. Additionally, care must be taken in detailing a series of interconnected perpendicular walls since the out-of-plane restraints along one wall may prevent slip on the perpendicular wall.
- In smaller buildings, it may be prudent to anchor all full height walls to the structural diaphragm above; in this way the partitions, if sheathed from floor-to-floor, provide additional lateral resistance for the building. Partial height partitions must be laterally braced to the structure above; braces may be required at 6 to 8 foot intervals; check code requirements.

- If partition walls will be used to provide lateral restraint for other nonstructural items, check that the walls and the lateral restraints at the top are adequate to resist the additional loading.
- New or improved restraint systems for steel stud partitions are under development; one such scheme was tested at Stanford University in July 2010 that allows for over 1.5" of displacement in any horizontal direction. Check the internet for additional restraint options.

Mitigation Examples

Figure 6.3.2.2-3 Bracing of partial height stud partition (Photo courtesy of Degenkolb Engineers).

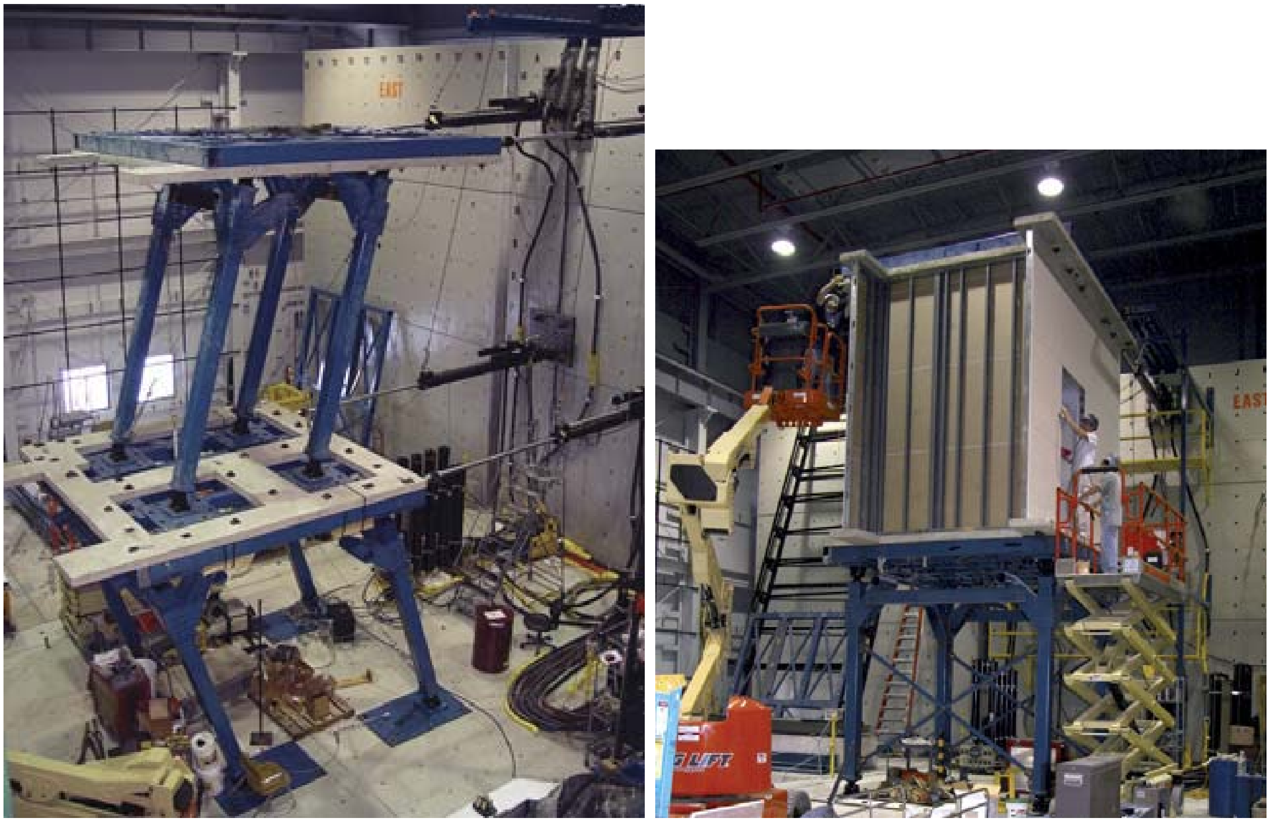
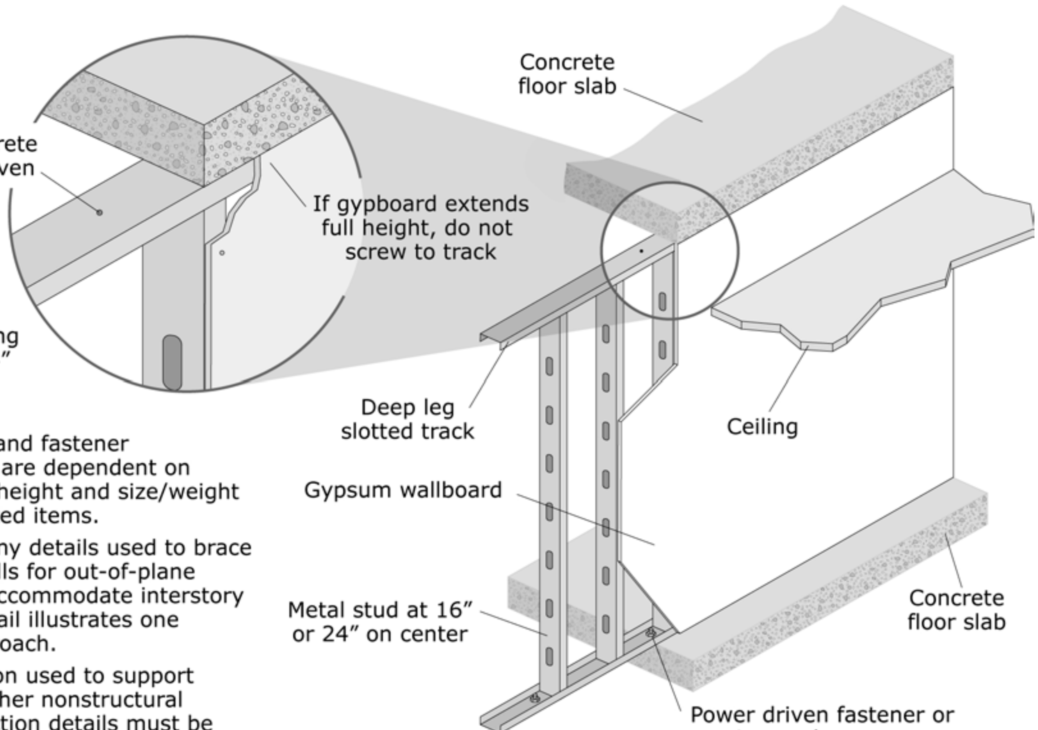


Figure 6.3.2.2-4 Two-story nonstructural component simulator at the University of Buffalo, SUNY shown at left. Preparation for dynamic testing of stud partitions for the NEES Nonstructural Project shown at right. Tests such as these improve understanding of the seismic behavior of nonstructural components (Photos courtesy of University of Buffalo, SUNY).

Mitigation Details



Notes: Stud and fastener sizes/spacing are dependent on floor-to-floor height and size/weight of wall-mounted items.

There are many details used to brace full height walls for out-of-plane loading and accommodate interstory drift. This detail illustrates one common approach.

Where partition used to support shelving or other nonstructural items, connection details must be adequate to resist imposed loads.

Figure 6.3.2.2-5 Full height nonbearing stud wall (ER).

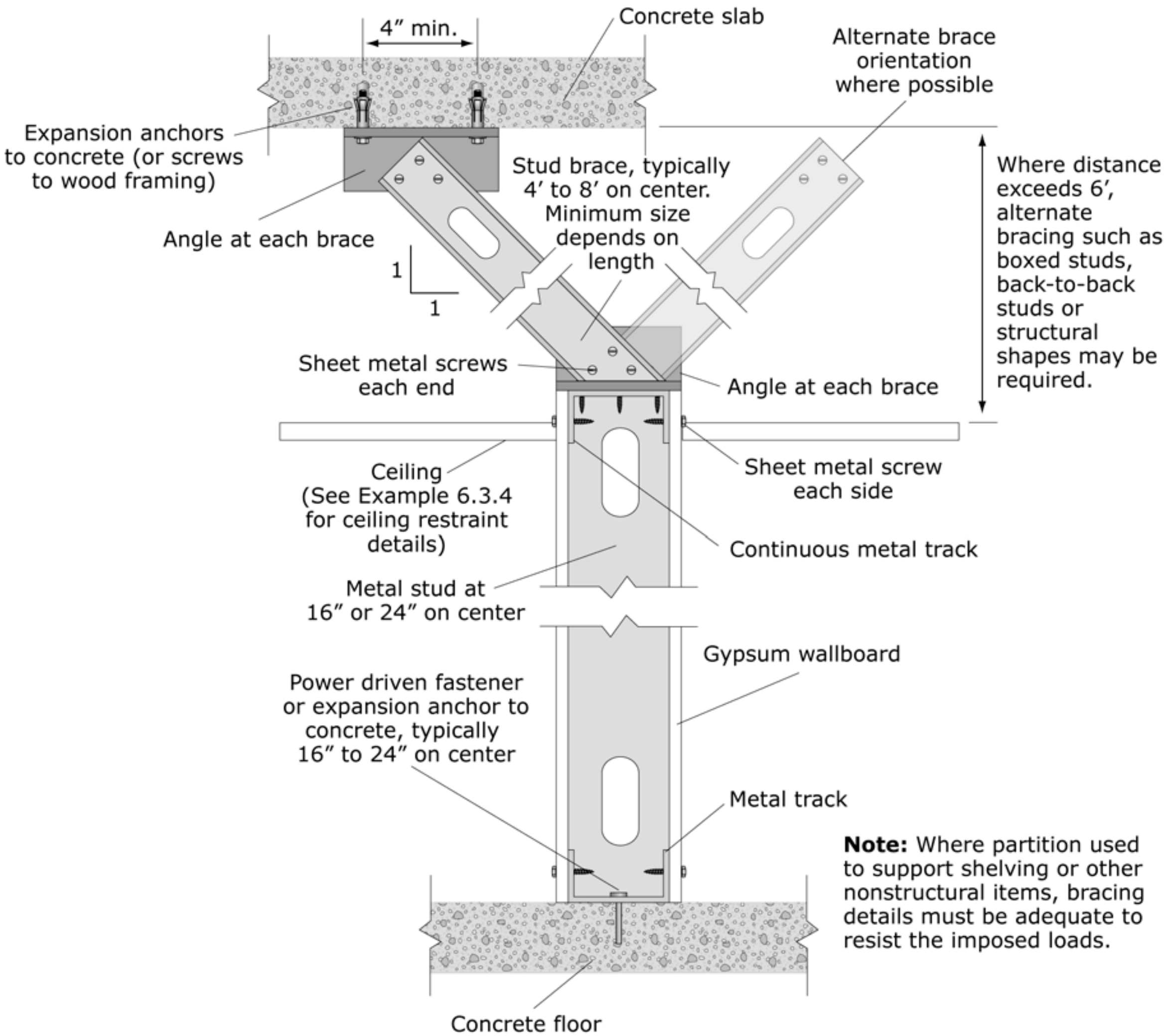


Figure 6.3.2.2-6 Partial height nonbearing stud wall (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.2 INTERIOR PARTITIONS

6.3.2.3 GLAZED PARTITIONS

Glazed partitions are often used in office corridors or around conference rooms to provide enhanced interior lighting. Glazing may be found in light, heavy, or demountable partitions; glazed partitions may be either full height or partial height. Glazing assemblies may be vulnerable to earthquake damage; glazed partitions must have lateral support but should be isolated from the movement of the surrounding structure.

TYPICAL CAUSES OF DAMAGE

- Glazing assemblies may be damaged as a result of either in-plane or out-of-plane loading unless properly detailed. Failure of glazed partitions may create falling hazards, block corridors, and endanger occupants attempting to exit from damaged buildings. Glazing is particularly vulnerable in assemblies where there is insufficient clearance in the glazing pockets or insufficient isolation from the structure to accommodate inter-story drifts.
- Full height glazed partitions in flexible structures may fail unless they are isolated from the building deformations. In addition to broken glass, the mullions, gaskets, or setting block may be damaged. Damage may also include cracked or spalled finishes surrounding the glazing, deformed partition framing, and failed connections. Partial height glazed partitions may damage ceiling framing to which they are attached or can fall out-of-plane unless they are laterally braced to the structure above. Particularly hazardous is glazing used at the top portion of partial height partitions where it can fall from increased height; such glazing is often used to allow light transmission but reduce sound transmission.
- Glazed partitions may be damaged by impact from unanchored furniture or contents or suspended items without appropriate sway bracing.

Damage Examples

Figure 6.3.2.3-1 Glass shards fallen from the top of partial height office partitions in the reception area during the magnitude-8.8 2010 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Figure 6.3.2.3-2 Damage to glazed doors at the Concepción airport in the 2010 Chile Earthquake. In the top photo the glazing in the sliding glass door shattered; in the lower photo the glass is intact but the door frames are misaligned (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Figure 6.3.2.3-3 Failed wood framed glazing assembly in the 2010 Chile earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). The wood framing was held in place by metal or rebar brackets embedded in the masonry wall. The adobe wall on the left of the door collapsed and the brackets on the right side pulled out of the brick masonry wall (lower right). The glazing assembly at the rear entrance of the chapel was anchored overhead to the wood balcony framing and was undamaged.

SEISMIC MITIGATION CONSIDERATIONS

- The design of glazed partitions depends on the calculated inter-story drift for the building. Glazing generally performs better with stiffer structural systems that have lower inter-story drift or where larger edge clearances are provided at the mullions. The building code ASCE/SEI 7-10, *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010), and rehabilitation standard ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings,* (ASCE, 2007) include minimum requirements for $\Delta_{fallout}$, the relative displacement that causes glass to fall from the glazing assembly, as a multiple of the design displacement and the importance factor. For specific requirements and exemptions, check local code provisions.

- Architectural Design for Earthquake (Charleson, 2007) provides discussion and graphics pertaining to seismic detailing for glazing and glazed partitions. In addition, the American Architectural Manufacturer's Association (AAMA) has published guidelines for testing glazing assemblies and determining $\Delta_{fallout}$. These guidelines may be obtained at www.aamanet.org.
- Glazing may be found in heavy, light, or demountable partitions; glazed partitions may be either full height or partial height. Anchorage details for heavy partitions are shown in Section 6.3.2.1, light partition details are shown in Section 6.3.2.2, and demountable partition details are shown in Section 6.5.5.2. The nonstructural surround must be self-supporting and not deliver loads to the glazing assembly from above or either side; thus, wall elements above the glazed portion may need to be suspended from above or have an adequate lintel so the weight does not bear on the glazing or mullions. A deep leg slip track could be installed either at the top of the mullion or at the structure above, depending on the structural framing configuration. Note that because glazed partitions must meet the seismic drift limits for glass components, glazed partitions may require additional or different bracing than a similar partition without glazing. Also note that where the partition is properly detailed to be isolated from the seismic inter-story drift of the surrounding structure, the glass-to-frame clearance required around each pane of glazing is reduced. Special care should be given when detailing glass on intersecting planes such as corners and reentrant corners as these locations are particularly vulnerable to damage.
- Safety glazing, such as laminated or tempered glass, may be required in areas adjacent to stairways or subject to human impact; check the applicable code for specific requirements. Use of safety glass will reduce the hazard in the event that some of the glazing breaks in an earthquake.
- All glass assemblies have become common for enclosing lobby areas or atria in large commercial buildings. These typically are suspended from specially designed steel framing and may include details such as glass fins and steel connecting hardware. These assemblies are typically left free to slip at the bottom and must be specially detailed at edges and corners to avoid impact with adjacent panes.
- Glazed partitions should not be used to provide lateral support to other nonstructural components such as book shelves, electrical panels, file cabinets, unless adequate lateral resistance can be shown. In addition, such items should not be located where they can tip, fall, or swing and break the partition glazing.

- The use of glazed partitions should be avoided in emergency exit corridors or stairways; limiting the height and area of partition glazing or using multiple smaller panes of glass may be less hazardous than larger and taller panes.

Mitigation Examples

Figure 6.3.2.3-4 Glazed partition supported at base with slip track at top; partition above glazing suspended and braced from above. Glazing subdivided into relatively small panels with ample clearance at mullions (Photo courtesy of Cynthia Perry, BFP Engineers).

Figure 6.3.2.3-5 Specialized glazing details for glass dome using specialty hardware, such as large sealant joints required to accommodate thermal movement and seismic deformations at the California Academy of Sciences, San Francisco, California (Photos courtesy of Cynthia Perry, BFP Engineers).

Mitigation Details

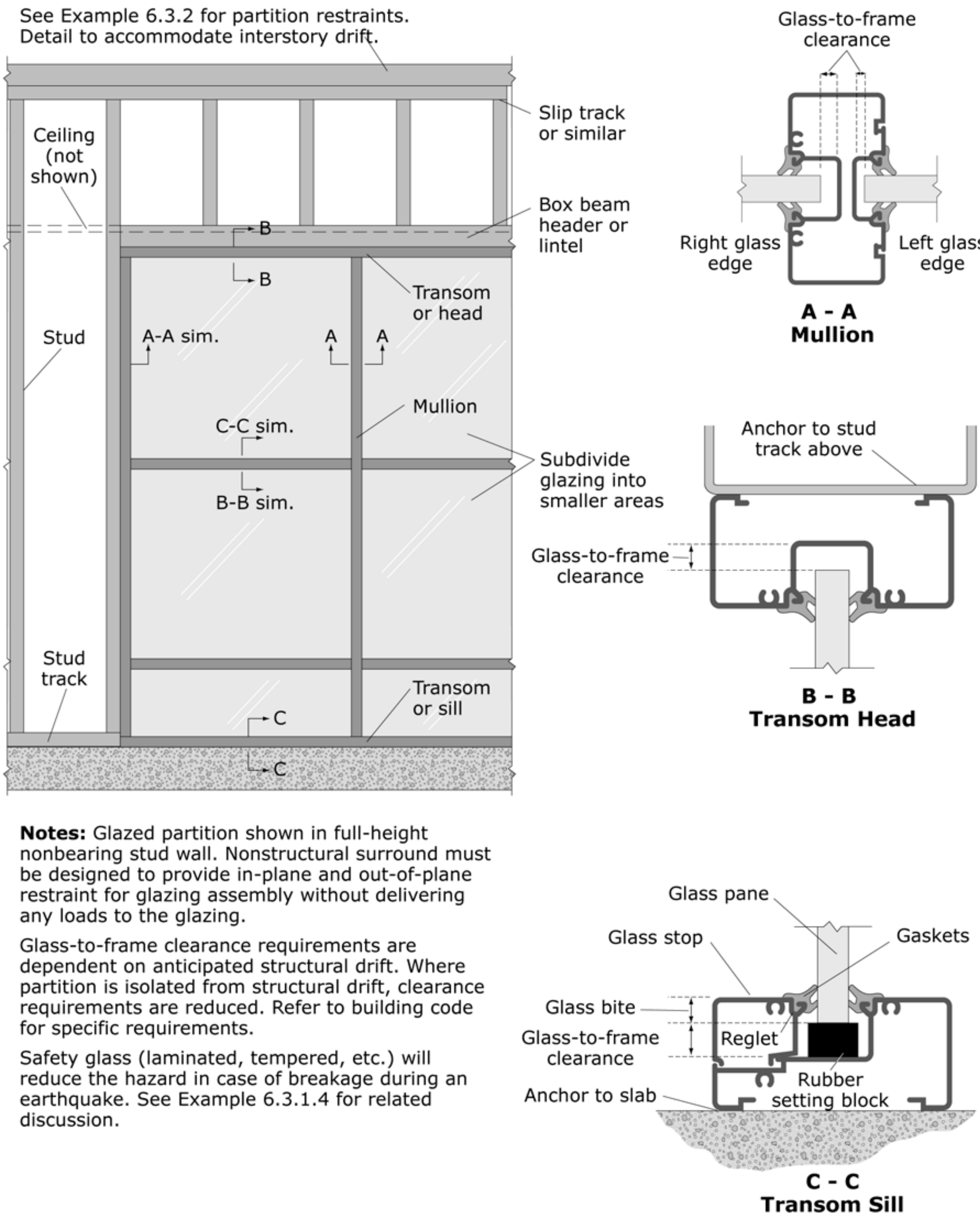


Figure 6.3.2.3-6 Details for full-height glazed partition (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.3 INTERIOR VENEERS

6.3.3.1 STONE, TILE AND MASONRY VENEER

Interior veneer may be either adhered or anchored; both types are addressed here. Veneer made of thin materials such as ceramic tile, masonry, corian or similar solid surface, and stone can be attached to a backing substrate with adhesive. Heavy veneers such as masonry, stone, or stone slab units weighing more than 20 psf must be anchored to the structure by mechanical means. To avoid becoming a falling hazard, veneers and their connections must be designed to accommodate the anticipated seismic drift. Alternatively, they must be attached to interior partitions which are isolated from the anticipated seismic drift of the structure.

TYPICAL CAUSES OF DAMAGE

- Adhered veneers are deformation sensitive and may crack or become dislodged due to deformation of the backing substrate. Veneer adhered directly to structural elements may be particularly vulnerable, for example, veneer adhered to a concrete or masonry shear wall may be damaged when the wall deforms. Poorly adhered veneer may come loose due to direct acceleration. Where veneer, such as tile, is used to provide a water barrier, such as in kitchens, restrooms, or showers, the adhesive and backing substrate may be damaged due to water intrusion if the mortar joints are cracked or deteriorated. In this case, whole sections of tile might come loose.
- Anchored veneers and their connections may be damaged by inertial forces and by building distortion, especially when located at corners and openings. Rigid connections may distort or fracture if they do not have sufficient flexibility to accommodate the seismic drift. In addition, veneer units may crack, spall, or become completely dislodged and fall.

Damage Examples

Figure 6.3.3.1-1 Damage to adhered tile veneer in residential bathroom and kitchen in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Ruben Boroschek & Associates). Tile is adhered to CMU infill partitions.

Figure 6.3.3.1-2 Damage to adhered tile veneer in locker room and kitchen at industrial facility in the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Tile was adhered to CMU partitions which were built integral with the concrete frame. While only a limited number of tiles were broken, equipment had to be disconnected and many tiles removed to repair cracks in the wall and facilitate the repair of the veneer.

SEISMIC MITIGATION CONSIDERATIONS

- Where interior veneer is attached to nonstructural walls or partitions, these partitions must be designed with adequate in-plane and out-of-plane support but detailed to accommodate the anticipated inter-story drift of the structural frame. Sections 6.3.1.1 and 6.3.1.2 provide additional information about adhered and anchored exterior veneers; the details used for interior veneers are similar, although interior and exterior finishes are typically installed by different trades.

- ASCE/SEI 7-10 *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010) contains a number of prescriptive requirements and limitations on the use of veneer. These include height limits, drift limits, deflection limits, limits on the use of combustible structural supports such as wood, mortar bed minimum thickness limits, and minimum tie spacing limits. Check the applicable code requirements when considering seismic mitigation options.
- Care must be taken in detailing corners, openings, edges and joints between structural elements and nonstructural substrates, such as a corner where a concrete masonry infill wall with veneer abuts a concrete column. While joints between individual tiles or stones may be grouted, movement joints may require a flexible sealant and bond breaker. Check manufacturer's recommendations for detailing under these special conditions.
- Adhered veneer placed directly on concrete or masonry shear walls is likely to be damaged during a design level earthquake since the shear wall is designed to deform to resist seismic loading. Cracking or spalling of adhered veneer on a shear wall is a sign that the shear wall has been damaged and may also be in need of repair.
- There are many vendors who supply veneer adhesion or anchoring systems. Some seismic veneer anchor examples for exterior veneers are shown in Section 6.3.1.2, and others can be found online. Figure 6.3.3.1-3 shows two examples of anchoring schemes for thin stone slabs as typically installed by specialty contractors. Both the supporting structure and the anchorage assembly must be designed to accommodate the anticipated inter-story drift.
- Existing veneer anchors should be checked periodically and corroded anchors should be replaced. Tie spacing should be compared with current code requirements to evaluate whether the anchorage is sufficient. Additional anchors may be installed to reduce the falling hazards. Adhered veneer used to provide a water barrier must also be periodically inspected and maintained; if not repaired, water intrusion may cause corrosion or deterioration of the backing substrate or structural supports.
- It may be prudent to remove interior veneer in exit corridors or above exits, especially if larger units are mounted above 10 feet.

Mitigation Details

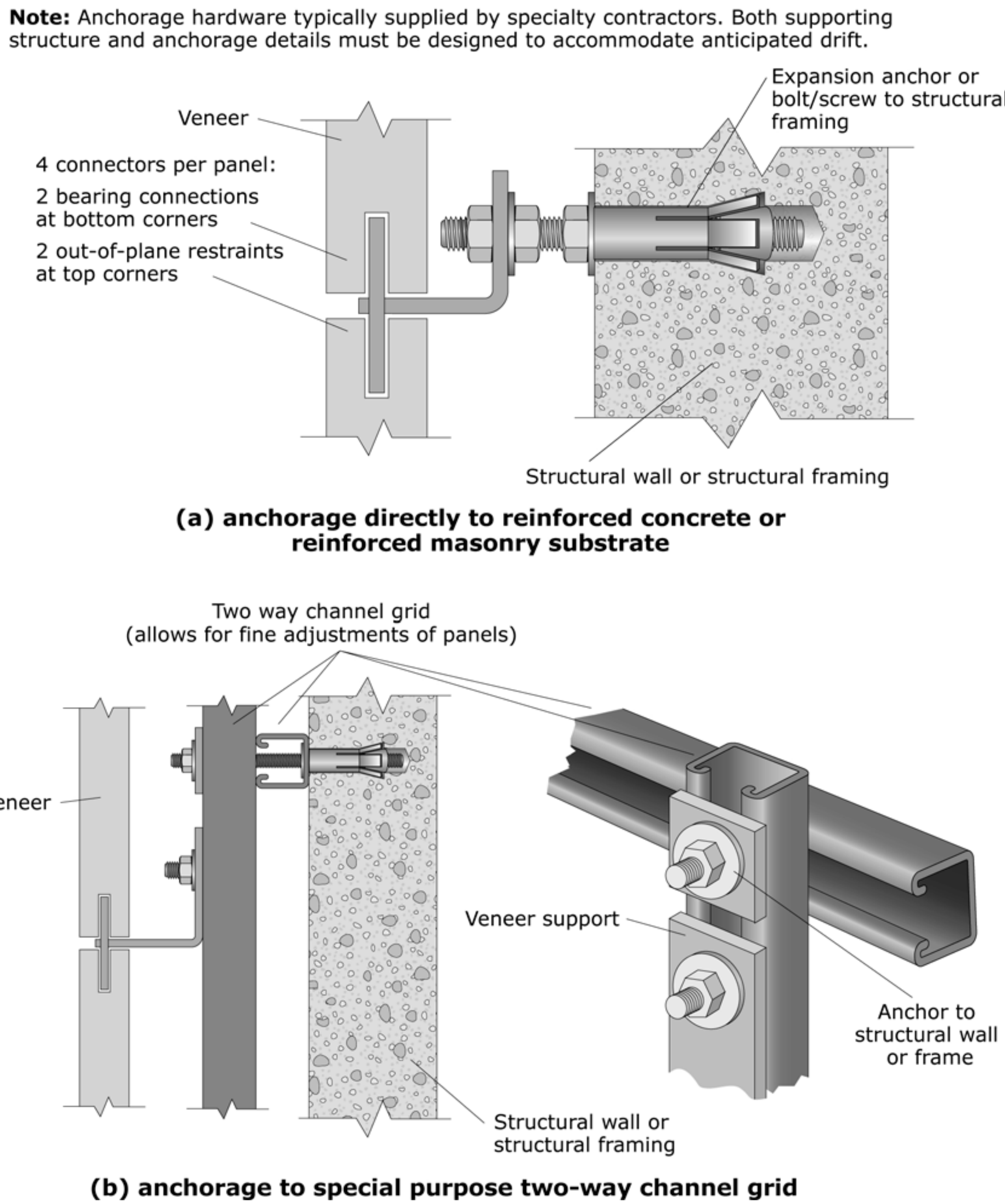


Figure 6.3.3.1-3 Detail for anchored interior veneer (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.4 CEILINGS

6.3.4.1 SUSPENDED ACOUSTIC LAY-IN TILE CEILING SYSTEMS

Suspended acoustic ceiling systems are used widely in many types of buildings. These ceiling systems often include lay-in lighting and openings for air diffusers and sprinklers heads.

TYPICAL CAUSES OF DAMAGE

- Differential movement of the ceiling relative to structural elements such as columns or walls or nonstructural elements such as partitions, sprinklers heads, or fixed lighting may damage the ceiling.
- Acoustical tiles may be dislodged and fall out of the ceiling grid; lights, diffusers, and sprinkler heads may swing and damage the ceiling; runners and cross runners in the grid may separate and fall. Ceiling systems are especially vulnerable at the perimeter or at penetrations, such as a column, pipe chase, or fixed lighting.
- Where lights, diffusers and other services within the ceiling do not have independent safety wires, these items can fall and create a hazard for occupants.
- Conflicts between ceilings and sprinkler heads are a common occurrence causing damage to both the ceiling and sprinkler heads as well as water damage due to sprinkler leaks.
- Ceiling failures may result in building evacuations and loss of functionality until the ceiling and utilities are repaired. In a hospital setting or clean lab, the failure of the ceiling system may introduce dust and debris, including asbestos, into the room below compromising its functionality. In the case of asbestos contamination, this may involve costly removal before functionality can be restored.

Damage Examples

Figure 6.3.4.1-1 Failure of suspended ceiling system including lights, air diffusers, and insulation in control room of an industrial plant in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of BFP Engineers).

Figure 6.3.4.1-2 Failure of suspended ceiling system including lights and air diffusers in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).

Figure 6.3.4.1-3 Generalized failure of ceiling grid, tiles, lights, and diffusers at the Los Angeles Hospital in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Figure 6.3.4.1-4 Fallen ceiling tiles at Talca Hospital in the 2010 Chile Earthquake, in spite of the use of clips as shown in detail at right. Most ceilings observed in Chile did not have seismic detailing (Photos courtesy of Bill Holmes, Rutherford & Chekene).

SEISMIC MITIGATION CONSIDERATIONS

- Standard practice for the seismic design of suspended acoustic lay-in tile ceilings is described in ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASCE, 2010), which is referenced in ASCE 7-10 Section 13.5.6. This standard supersedes several previous CISCA standards.

- For ceilings in Seismic Design Category C, the objective of these standards is to provide an unrestrained ceiling that will accommodate the movement of the structure during a seismic event. This is achieved by specifying the strength of grid connectors, frequency of hangers, perimeter closure angles, edge clearances, etc. For ceilings in Seismic Design Category D, E & F, the objective of these standards is to provide a restrained ceiling with connection to the perimeter wall and with rigid or non-rigid bracing assemblies. This is achieved by specifying the strength of grid elements, grid connections, frequency of hangers and lateral bracing assemblies, 2" minimum perimeter closure angles, minimum edge clearances, etc. For Seismic Design Category D, E & F, lateral bracing assemblies are required for all ceiling areas greater than 1000 sq. ft. There are several exemptions as follows:
    - Seismic detailing is not required for suspended ceilings less than or equal to 144 sq. feet that are surrounded by walls or soffits that are laterally braced to the structure (this exemption applies to heavy or light suspended ceiling systems).
    - For ceilings in Seismic Design Category C weighing less than 2.5 psf, special seismic perimeter closure details are required to provide an unrestrained ceiling; bracing assemblies are not required.
    - Ceilings weighing above 2.5 psf in Seismic Design Category C and ceilings in Seismic Design Categories D, E & F are detailed to provide a restrained ceiling; nevertheless, they do not require bracing assemblies unless they are larger than 1000 sq. ft.
- For Seismic Design Category D, E & F, these details typically include requirements for perimeter closure that provides fixity along two adjacent sides and allows ¾" of slip on the opposite sides as well as periodic bracing assemblies in ceilings larger than 1000 sq. ft. ASTM E580 includes requirements for the strength of connections between grid elements, minimum size (2") for the closure angle, requirements for seismic separation joints for ceilings larger than 2500 sq. ft., requirements for the support of lighting and mechanical services, etc. Check with ASTM E580 for applicable spacing, exemptions, and other requirements.
- Where lights and diffusers and supported by the ceiling grid, either an intermediate duty or heavy duty grid must be used and supplementary framing and hanger wires may be required to provide direct support for such items. For instance, ASTM E580 requires heavy duty main runners with a load carrying capacity of 16 lb/ft for Seismic Design Category D, E and F. If cross runners with a load carrying capacity less than 16 lbs/ft are specified, and the corner of any light fixture is supported on two adjacent sides by these intermediate duty cross runners, then a supplementary hanger wire must be attached to

the grid within 3” of each such corner. ASTM E580 includes several figures showing examples where these supplementary wires are required. These supplementary hanger wires are not required where heavy duty cross runners are specified; for instance, DSA IR 25-5 *Metal Suspension Systems for Lay-in Panel Ceilings* (California Department of General Services, 2009c), requires all lights to be supported by heavy duty runners. In order to minimize their potential falling hazard, lights, diffusers and similar items are required to have independent safety wires attached directly to the structure. The number and configuration of these safety wires varies depending on the size and weight of the items. See Examples 6.4.6.2 and 6.4.9 for additional requirements for ail diffusers and lights, respectively.

- Seismic bracing assemblies for suspended ceilings typically include a vertical compression strut and diagonally splayed wire braces as shown in Figure 6.3.4.1-8. Rigid bracing assemblies, such as those shown to brace overhead piping in Section 6.4.3 may also be used.
- ASTM E580 includes other requirements for clear openings for sprinkler heads, seismic separation joints, ceiling penetrations, and consideration of consequential damage and seismic interaction effects.
- The Division of the State Architect sets forth ceiling standards for California schools in DSA IR 25-5. This reference is a useful tool for designing in areas of potentially severe seismic shaking. In California, schools require ceiling bracing assemblies at a spacing of not more than 12 feet in each direction; essential services buildings require bracing assemblies at a spacing of not more than 8 ft. by 12 ft. on center. DSA requirements differ slightly from those in ASTM E580; check the applicable jurisdiction for specific requirements.
- Ceiling details in Figures 6.3.4.1-6, 7, 8 and 9 are for Seismic Design Category D, E and F where the total ceiling weight does not exceed 4 psf or Seismic Design Category C where the total ceiling weight is between 2.5-4 psf. These are adapted from CA DSA IR 25-5 and ASTM E580. These figures are shown with heavy duty main runners and cross runners as required by DSA IR 25-5; see discussion in text regarding the requirement in ASTM E580 for supplementary hanger wires at light fixtures supported by intermediate duty cross runners. Check the applicable jurisdiction; in some cases, ceilings heavier than 4 psf, or those with a plenum larger than a certain threshold, may require engineering. See sources for additional information, updates, or for connection details and special conditions not shown.

- There are shake table tests of ceilings which show that systems perform better when the tile almost nearly fills the available space and has ample overlap on the runners. These systems also have fewer tiles drop in tests than systems with smaller tiles.
- ASCE 7-10 Section 13.5.6.3 includes a discussion of "integral construction" where the grid, panels, lights, piping, and other overhead services are shop assembled in modules and bracing is provided for the whole assembly. These are included as an alternative to the details shown here. Check the internet for proprietary systems or systems pre-approved for use in your jurisdiction.
- Safety wires are required for lights and mechanical services in suspended acoustic tile ceilings to prevent them from falling. Refer to Sections 6.4.9 and 6.4.6.2 for additional information. As noted above, supplementary hanger wires for the ceiling grid may also be required. The weight of supported items should never exceed the carrying capacity of the ceiling grid. Special details are required for heavy lighting or heavy mechanical items; these should be supported directly from the structure above and not depend on the ceiling grid for vertical or lateral support. For such fixed items, perimeter closure details may be required for the ceiling to prevent impact with the ceiling system.

Mitigation Examples

Figure 6.3.4.1-5 Compression struts and diagonal splayed wires are used to limit the movement of suspended acoustic tile ceilings. Per ASTM E580, this type of bracing assembly is required for ceiling areas larger than 1000 sq. ft. in Seismic Design Category D,E & F. (Photo courtesy of Maryann Phipps, Estructure).

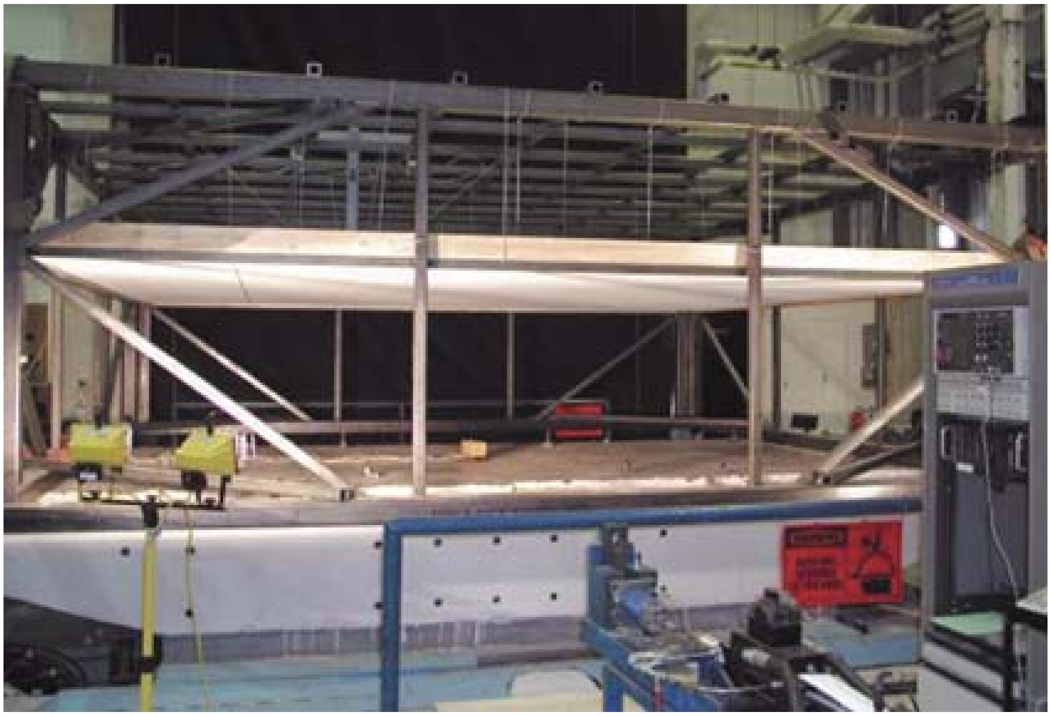


Figure 6.3.4.1-6 Shake table testing of a proprietary suspended acoustic lay-in tile ceiling at MCEER (Photo courtesy of University of Buffalo, SUNY). Additional testing of these systems will help improve our understanding of their failure modes and help inform the design of more resilient systems.

Mitigation Details

Ceiling details in Figures 6.3.4.1-7, 8, 9 and 10 are for Seismic Design Category D, E and F where the total ceiling weight does not exceed 4 psf or Seismic Design Category C where the total ceiling weight is between 2.5-4 psf. These are adapted from DSA IR 25-5 and ASTM E580. These figures are shown with heavy duty main runners and heavy duty cross runners as required by DSA IR 25-5; see discussion in text regarding the requirement in ASTM E580 for supplementary hanger wires at light fixtures supported by intermediate duty cross runners. Check the applicable jurisdiction; in some cases, ceilings heavier than 4psf, or those with a plenum larger than a certain threshold, may require engineering. See sources for additional information, updates, or for connection details and special conditions not shown.

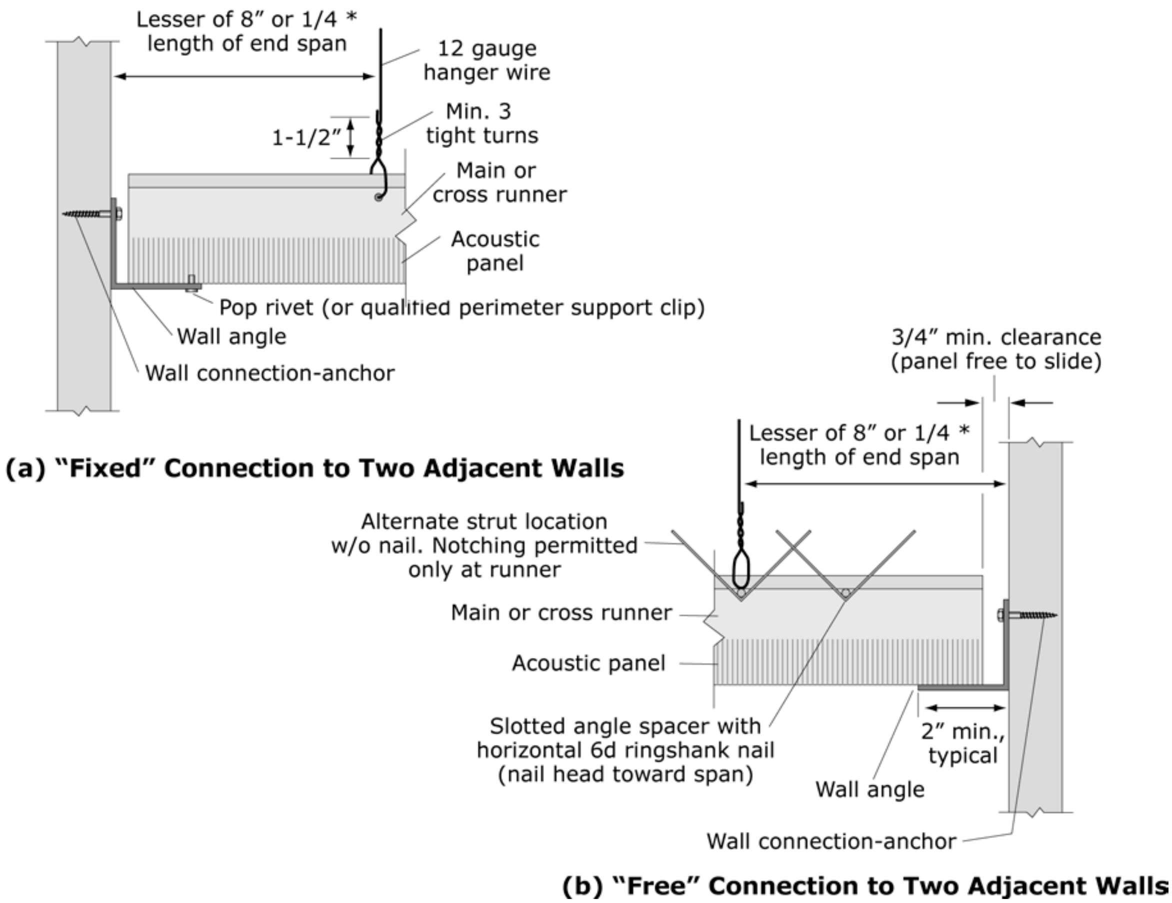
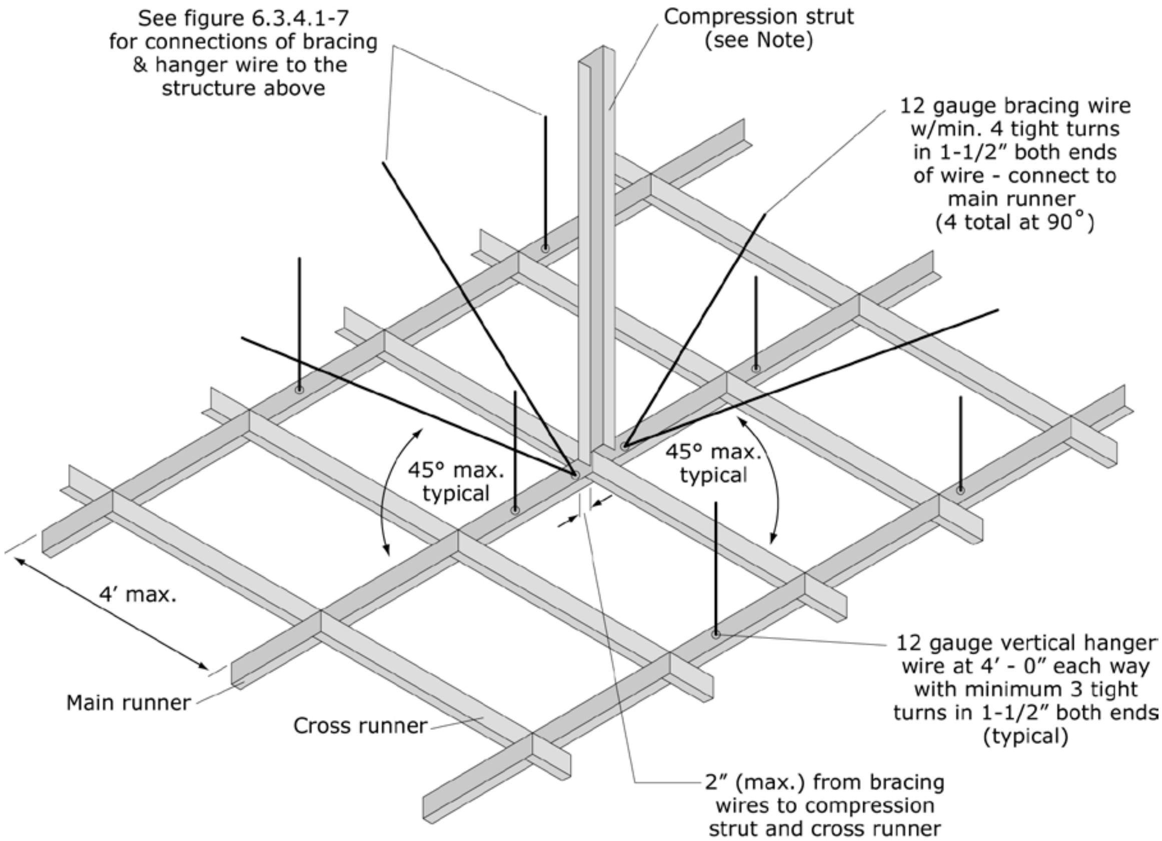


Figure 6.3.4.1-7 Suspension system for acoustic lay-in panel ceilings – edge conditions (PR).



Note: Compression strut shall not replace hanger wire. Compression strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4″ min. expansion anchor to structure. Size of strut is dependent on distance between ceiling and structure (l/r ≤ 200). A 1″ diameter conduit can be used for up to 6′, a 1-5/8″ X 1-1/4″ metal stud can be used for up to 10′

Per DSA IR 25-5, ceiling areas less than 144 sq. ft, or fire rated ceilings less than 96 sq. ft., surrounded by walls braced to the structure above do not require lateral bracing assemblies when they are attached to two adjacent walls. (ASTM E580 does not require lateral bracing assemblies for ceilings less than 1000 sq. ft.; see text.)

Figure 6.3.4.1-8 Suspension system for acoustic lay-in panel ceilings – lateral bracing assembly (PR).

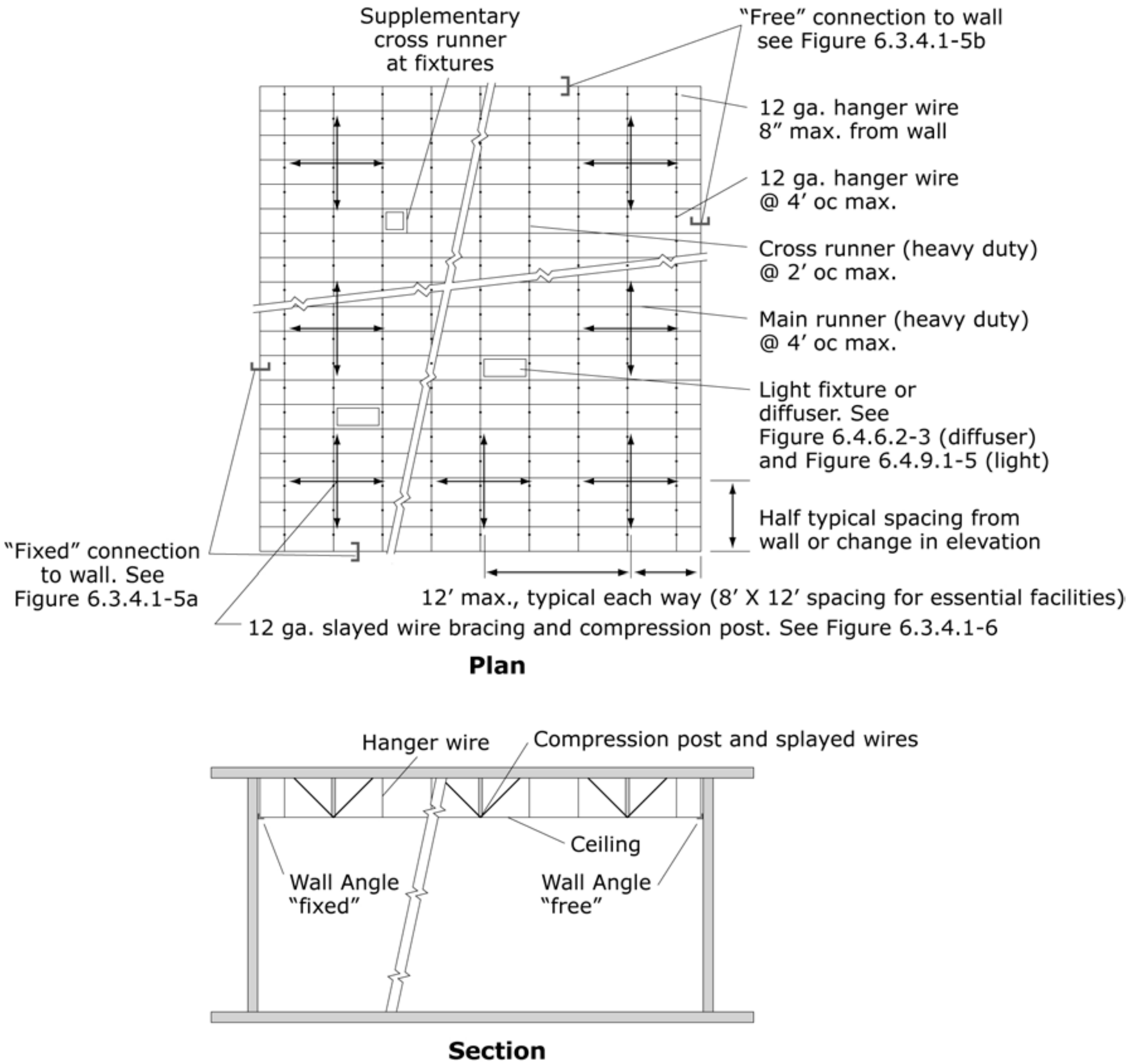
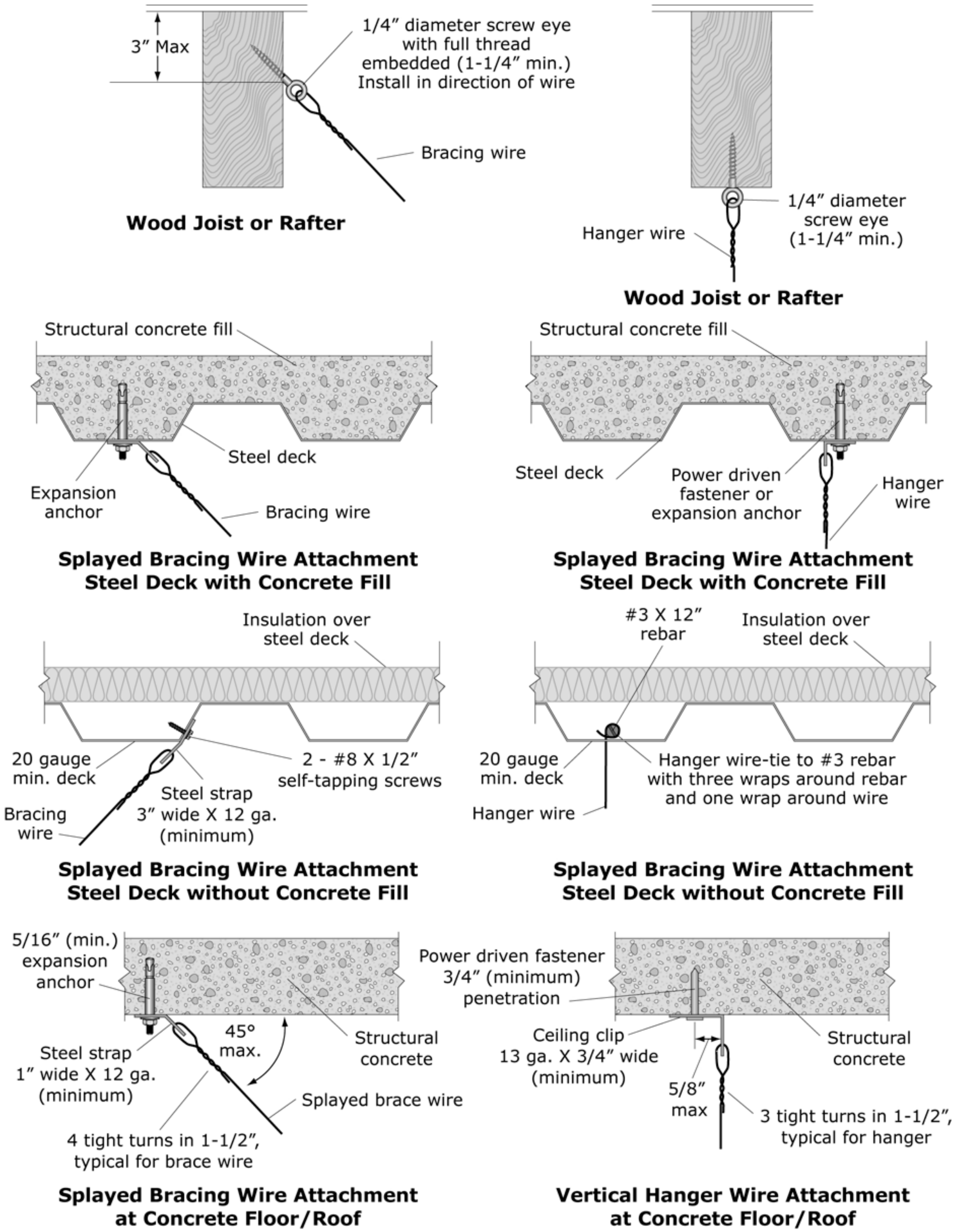


Figure 6.3.4.1-9 Suspension system for acoustic lay-in panel ceiling – general layout (PR).



Note: See California DSA IR 25-5 (06-22-09) for additional information.

Figure 6.3.4.1-10 Suspension system for lay acoustic lay-in panel ceiling – overhead attachment details (PR).

6.3 ARCHITECTURAL COMPONENTS

6.3.4 CEILINGS

6.3.4.2 CEILINGS APPLIED DIRECTLY TO STRUCTURE

Ceiling finishes such as gypsum board, interior lath and plaster, or exterior stucco soffits may be applied directly to structural elements such as wood ceiling joists, beam soffits, or the underside of structural slabs. These overhead finish materials may pose a falling hazard if the finish materials and any backing substrate are not anchored to the structure with positive attachments.

TYPICAL CAUSES OF DAMAGE

- Vintage lath and plaster ceilings may fall if the wood or metal lath is not adequately secured to the structure above or if the plaster has separated from the lath. Even well secured ceilings may exhibit x-cracking in buildings with flexible diaphragms or cracking around the edges where the ceiling and walls meet or at locations with seismic joints that have not been properly detailed. These ceilings may be particularly vulnerable if they have deteriorated due to roof or plumbing leaks.
- Stucco soffits on exterior surfaces, such as the underside of balconies or canopies, may fall if the wood or metal lath or finish materials are not adequately secured to the structure above or if the attachments have corroded or the components have deteriorated due to long term exposure or leakage from the roofing or decking above. Stucco soffits on cantilevered balconies or canopies may be particularly vulnerable as they often experience higher vertical accelerations than other structures.
- Large expanses of ceiling attached directly beneath flexible diaphragms may be damaged unless the ceiling is properly detailed with two adjacent sides attached and the opposite sides free and is subdivided into smaller areas (<2500 sq ft) with seismic expansion strips. Damage may occur around the perimeter, at changes in elevation, or at corners, columns, or other obstructions.

Damage Examples

Figure 6.3.4.2-1 Damage to metal lath and plaster ceiling applied to the underside of the concrete slab in 10-story residential building in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). The damage occurred due to pounding at the interface between two wings of the structure.

Figure 6.3.4.2-2 Damage to stucco soffit of historic church in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Stucco applied directly to the underside of the slab above without furring; portion at left has fallen, portion at right delaminated.

Figure 6.3.4.2-3 Damage to soffit paneling and wood framing at hotel in the 2010 Chile Earthquake; panels and wood framing show signs of prior water damage and deterioration. Note also damage to storefront glazing and glass doors (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

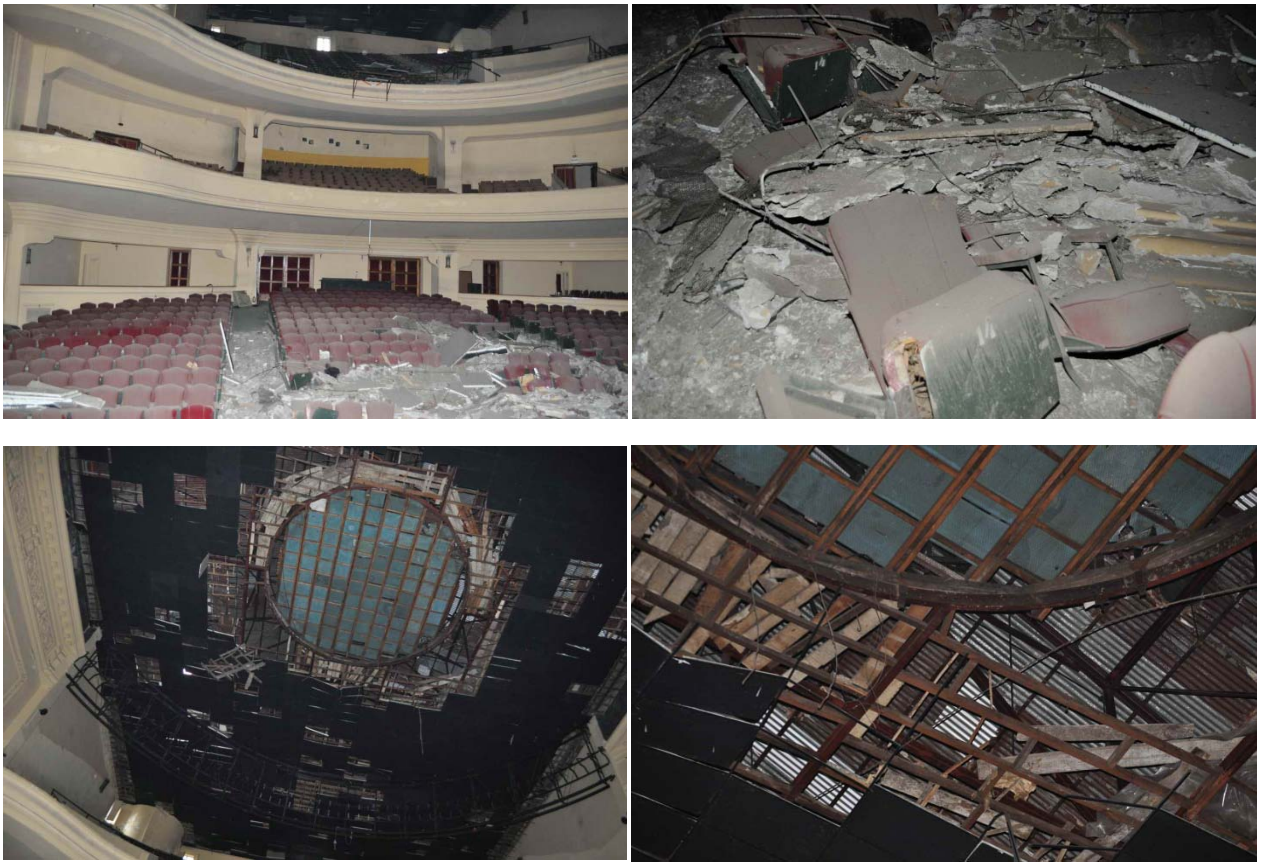


Figure 6.3.4.2-4 Damage to theater ceiling where foam panels and grid came down over orchestra seating and in upper balcony at the Municipal Theater Valparaiso in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). A circular section of metal lath and plaster collapsed completely. It appears the metal lath may have only been attached around the perimeter to wood furring added in the plane of the steel framing; circular area of wired glass is in a plane above the level of the wood furring. Black panels are lightweight foam supported by a grid attached directly to the wood furring.

Figure 6.3.4.2-5 Extensive failure of ceiling in the main terminal of the Santiago airport in the 2010 Chile Earthquake. Metal panels with lights and diffusers hung from furring on short metal tabs; these remained in place but detail at lower left shows they also sustained some damage. Furring channels still in place throughout ceiling but majority of lightweight ceiling panels and much of the cross furring came down as shown at lower right photo of exterior soffit with same system (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

SEISMIC MITIGATION CONSIDERATIONS

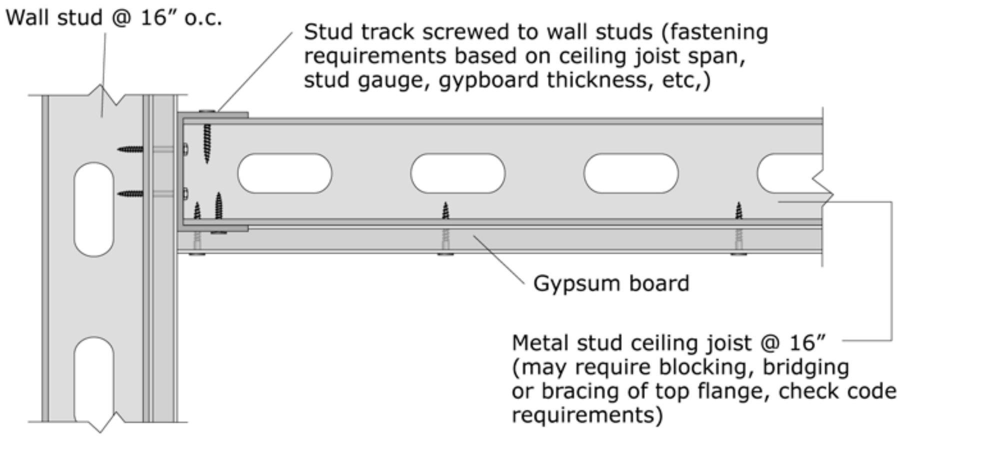
- Provide positive connections from the gypsum board, plaster or stucco finish materials to the furring and from the furring to the structure above. Protect these connections from water damage or corrosion. Check local codes for specific requirements or exemptions; in many cases these ceilings do not require special seismic detailing as long as the installation meets current industry standards.
- It may be prudent to reduce the standard connector spacing on stucco soffits or finishes mounted beneath cantilevered balconies or canopies which may experience large vertical accelerations during an earthquake. Note that finishes with exterior exposure such as soffits also need to be designed for wind.
- Gypsum board ceilings are frequently used to meet requirements for fire-rating or sound proofing or both. Rated systems may include combinations of metal decking, wood subflooring, wood or metal joists, insulation, resilient furring strips, and one or several layers of gypsum board. While rated systems are typically proprietary, care must be taken to insure that appropriate fasteners are used for each successive layer and that they are installed with adequate penetration into the joists or furring strips. These multi-layer systems get increasingly heavy and also have increased in-plane stiffness. In some instances, care must be taken with the perimeter details to provide seismic expansion joints and to allow relative movement with the walls but maintain the fire-rating. Availability of certified systems with seismic detailing wherever sound or fire proofing is required should be checked and these systems must be installed exactly as specified and as tested otherwise the certification is not valid.
- Vintage lath and plaster ceilings still exist in many older structures. These ceilings should be in good condition with the lath securely fastened to the structure and the plaster secured to the lath. The most reliable way to upgrade these ceilings would be to remove and replace with a code compliant ceiling system. Where it is important to match other vintage finishes, screw attached metal lath with a new plaster finish can be used. As an alternative to replacement, screwing 1x2 wood strips at 16 in centers into the joists from below may serve as a safety net (See Figure 6.3.4.2-9). Some ornate theatre ceilings have been encapsulated from below with netting to reduce the falling hazard; such netting and all its attachments must be designed to contain any falling debris.

Mitigation Examples

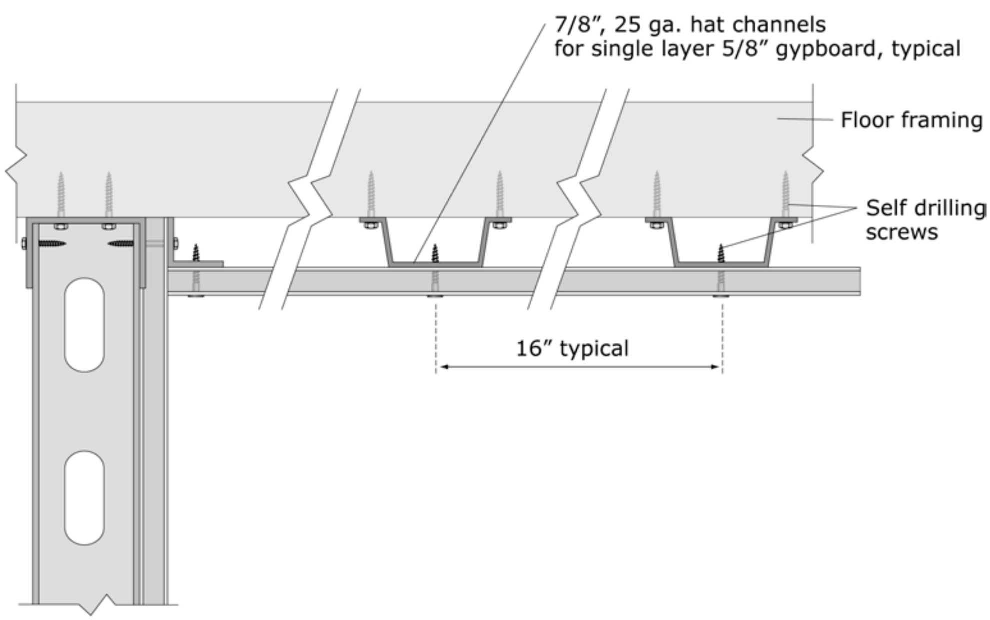
Figure 6.3.4.2-6 Mitigation examples with 1-1/2" hat channels at 16" on centers screwed in place with #12 self drilling screws and furring strips ready to receive gypsum board (Photo courtesy of Excalibur Steel). No special seismic details are required for this type of ceiling where the gypsum board is well secured directly to furring strips.

Figure 6.3.4.2-7 View of typical wood lath and plaster ceiling from the 1920's from above (Photo courtesy of Cynthia Perry, BFP Engineers). The wood lath is well nailed to the underside of the ceiling joists. This type of ceiling typically remains intact during an earthquake but may require crack repair and painting. Where the plaster has delaminated from the lath due to age or water leakage, wood strips could be installed from below as in Figure 6.3.4.2-8.

MITIGATION DETAILS



a) Gypsum board attached directly to ceiling joists



b) Gypsum board attached directly to furring strips (hat channel or similar)

Note: Commonly used details shown; no special seismic details are required as long as furring and gypboard secured. Check for certified assemblies (UL listed, FM approved, etc.) if fire or sound rating required.

Figure 6.3.4.2-8 Gypsum board ceiling applied directly to structure (NE).

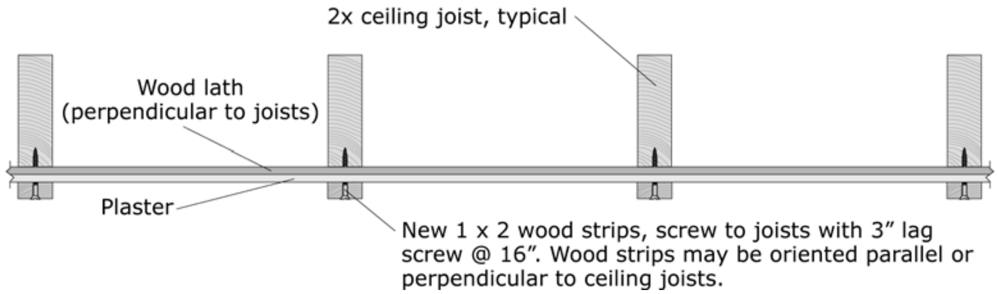


Figure 6.3.4.2-9 Retrofit detail for existing lath and plaster (NE).

6.3 ARCHITECTURAL COMPONENTS

6.3.4 CEILINGS

6.3.4.3 SUSPENDED HEAVY CEILINGS

This category covers several different types of overhead ceilings suspended from above including dropped furred gypsum board ceilings and suspended lath and plaster ceilings. Suspended ceilings with wood or metal panels would also fit into this category. These systems typically have finish material attached to a two-way furring grid which is suspended from above. In order to reduce damage and prevent falling hazards the finish material must be well secured to the furring grid. Damage can be reduced if the ceiling is attached to the walls along two adjacent sides but separated from the walls along the opposite two sides and the furring grid is laterally braced to the structure above.

TYPICAL CAUSES OF DAMAGE

- Suspended heavy ceilings may be damaged both by direct acceleration and by deformation. Direct acceleration may cause connectors to become loose or deform, and differential movement of the ceiling relative to structural elements such as columns or walls or nonstructural elements such as partitions, lights, diffusers, or sprinklers may also damage the ceiling.
- As these systems are heavier than acoustic tile ceilings, the consequences of failure may be more hazardous for occupants since both the finish material and the furring grid may fall. Ceiling failures are often costly because the space underneath may be unusable while the ceiling is repaired or replaced.
- Ceiling finishes may crack unless adequately isolated from the motion of the surrounding structural and nonstructural elements. Crack repair in gypsum board and plaster ceilings is a common expense following earthquakes.

Damage Examples

Figure 6.3.4.3-1 Damage to ornate wire lath and plaster ceiling in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Wire lath is attached to arches or to wood furring suspended from the roof framing.

Figure 6.3.4.3-2 Damage to suspended metal panel ceiling system and fire sprinklers at Concepción airport, primarily at far end and around column obstructions in the 2010 Chile Earthquake (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates). The metal panel was strong enough to fail the sprinkler head shown at lower left.

Figure 6.3.4.3-3a Complete collapse of a large suspended gypsum board ceiling over a swimming facility in Japan (Photo courtesy of Shojiro Motoyui, Tokyo Institute of Technology). This type of failure has been replicated on the E-defense shake table and occurs when the U-shaped clip holding the cross furring (M-bar) to the main runners (channel) opens into a V-shape and drops the furring grid. This type of failure is not common in the U.S.

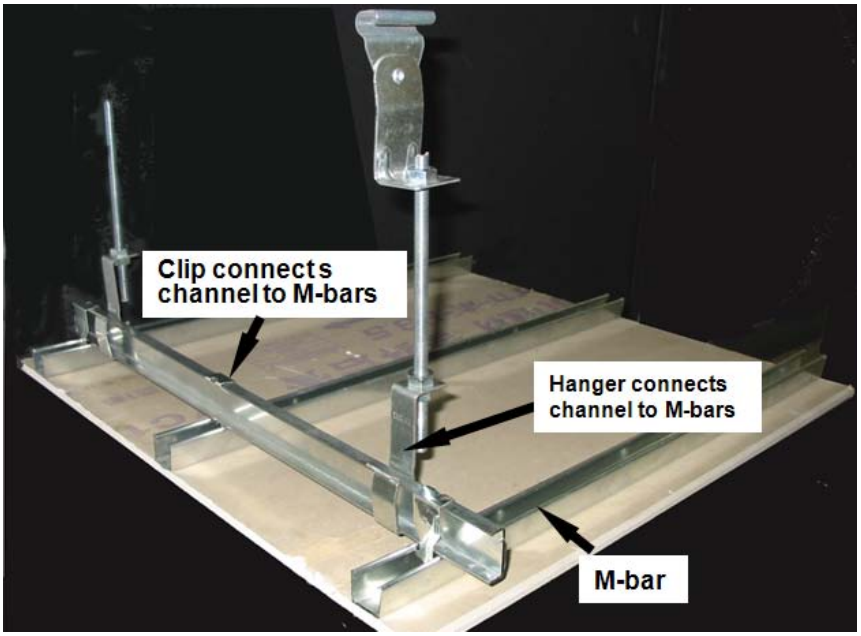


Figure 6.3.4.3-3b Schematic view of Japanese drywall ceiling grid. These ceilings are also typically installed with lateral bracing and 200mm edge clearance. Clip shown at lower right opens when the M-bar slides back and forth relative to the main runner, particularly those located near a diagonal brace. This type of clip is not common in the U.S (Source: "Dynamic characteristics of Japanese style of ceiling," Motoyui, S., Satoh, Y., and Kawanishi, T. *Proceedings 7CUEE & 5ICEE*, March 2010).

Figure 6.3.4.3-4 Collapse of exterior soffit at Jefferson Elementary School in Calexico in the 2010 Baja California Earthquake; approximately 1200 sq ft of soffit collapsed at this school built in the 1960's (Photo courtesy of Baja Earthquake Reconnaissance Team, Earthquake Engineering Research Institute (EERI), published in the EERI July 2010 Newsletter).

SEISMIC MITIGATION CONSIDERATIONS

- Section 13.5.6 of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010), contains requirements for special seismic perimeter details and lateral bracing assemblies for suspended ceilings but includes several significant exemptions from these requirements as follows.
    - Seismic detailing is not required for suspended ceilings less than or equal to 144 square feet that are surrounded by walls or soffits that are laterally braced to the structure (this exemption applies to heavy or light suspended ceiling systems).
    - Seismic detailing is not required for suspended ceilings constructed of screw- or nail-attached gypsum board on one level (constructed in a single plane) that are surrounded by and connected to walls or soffits that are laterally braced to the structure above. Note that this exemption does not apply to plaster ceilings or

to gypsum board ceilings on multiple levels (constructed in more than one ceiling plane elevation).

- Special seismic detailing may be required for other heavy ceilings such as plaster, wood or metal panels, or for gypsum board ceilings at multiple levels. For these cases, the details are configured similar to those used for acoustic ceilings with more frequent bracing to account for the increased weight. Seismic bracing for suspended heavy ceilings typically includes a vertical compression strut and diagonally splayed wire braces as shown in Figure 6.3.4.3-8. Rigid bracing (strut or cold-formed steel) is sometimes used in lieu of splayed wire bracing and compression posts. Special perimeter details typically include 2" wide perimeter closure angles, fixed attachments on two adjacent walls and clearance of at least ¾" from the two opposite walls as shown in Figure 6.3.4.3-6.
- Details shown in Figures 6.3.4.3-6, 6.3.4.3-7, and 6.3.4.3-8 are based on requirements for schools in California. The Division of the State Architect sets forth ceiling standards for California schools in DSA-IR 25-3 *Drywall Ceiling Suspension, Conventional Construction – One Layer* (California Department of General Services, 2005b). This standard refers to DSA-IR 25-5 *Metal Suspension Systems for Lay-in Panel Ceilings* (California Department of General Services, 2009c) for specific details regarding the bracing assembly. These references are useful tools for designing in areas of potentially severe seismic shaking or in jurisdictions where bracing is required. In California, ceiling bracing assemblies at a spacing of not more than 12 feet in each direction are required in schools and bracing assemblies at a spacing of not more than 8 ft by 12 ft on center, as shown in Figure 6.3.4.3-6, are required in essential services buildings.
- This section provides prescriptive details for suspended gypsum board ceilings where the grid is composed of channel sections for the main runners with hat channels wired below as the cross furring. Check with manufacturers for alternative proprietary systems that use T-bars for both the main and cross runners.
- Vintage lath and plaster ceilings are typically hung with wood hangers and runners without consideration of seismic design forces. Diagonal 45 degree splay bracing wires can be added at select wood hanger locations (for instance, 4 ft by 6 ft) to brace these ceilings. Some jurisdictions, such as the Salt Lake City School District, require that vintage lath and plaster ceilings be removed and replaced with compliant ceiling systems. Where historic preservation considerations require and the local codes permit, replacement plaster ceilings may be constructed with screw-attached metal lath and dedicated bracing. As a lower cost alternative to replacement in wood framed construction, the seismic risk posed by a plaster ceiling can be reduced by screwing 1x2

wood strips at 16" centers into wood joists from below (oriented perpendicular to the joists) to serve as a safety net. Some ornate theatre ceilings have been effectively encapsulated from below with netting to reduce the falling hazard; such netting and all its attachments must be designed to contain any falling debris.

- Ceiling anchorage needs to be coordinated with the anchorage for lighting, air diffusers, and sprinkler lines. All recessed or drop-in light fixtures and diffusers must be supported directly by main runners or by supplemental framing with positive attachment to main runners. In order to minimize their potential falling hazard, lights, diffusers and similar items are required to be independently supported by the structure, typically with a minimum of two wires, as discussed in Sections 6.4.6.2 and 6.4.9.3. In some locations and occupancies, penetrations for sprinkler heads in ceilings braced with splayed wire bracing are required to have a 2 inch oversized opening to allow for free movement of 1 inch in all horizontal directions. Check local code requirements.
- Mechanical connectors between the component parts of the ceiling assembly must be chosen carefully to avoid failures. Catastrophic failures of ceiling systems in Japan have been replicated during shake table testing because the U-shaped mechanical clip used to hang the cross furring from the main runner can open during an earthquake, dropping the cross furring and drywall as shown in Figures 6.3.4.3-3.

Mitigation Examples

Figure 6.3.4.3-5 Details of suspended and braced gypsum board ceiling in California hospital. Rigid bracing is provided at 6 ft by 8 ft on centers. Note cross furring saddle tied to black channel (main runner) from below; supplementary framing for lights runs parallel to cross furring and saddle tied to main runner from above (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details

Per ASCE 7-10, suspended ceilings constructed of screw- or nail-attached gypsum board on one level that are surrounded by and connected to walls or soffits that are laterally braced to the structure above are exempt from any special seismic design requirements.

The exemption above does not apply to suspended plaster ceilings, other heavy ceilings or to gypsum board ceilings at more than one level or that are not adequately supported by surrounding walls; these may require bracing assemblies and special edge details such as those shown here. Check applicable code requirements. Details in Figures 6.3.4.3-6, 7, and 8 are adapted from California DSA IR 25-3 (revised 7-21-05) that provides prescriptive details for a single layer of suspended gypsum board; check with DSA for additional details and the latest requirements (http://www.dsa.dgs.ca.gov/Pubs/IRManual.htm). These details are shown with standard steel shapes; proprietary T-bar systems are also available.

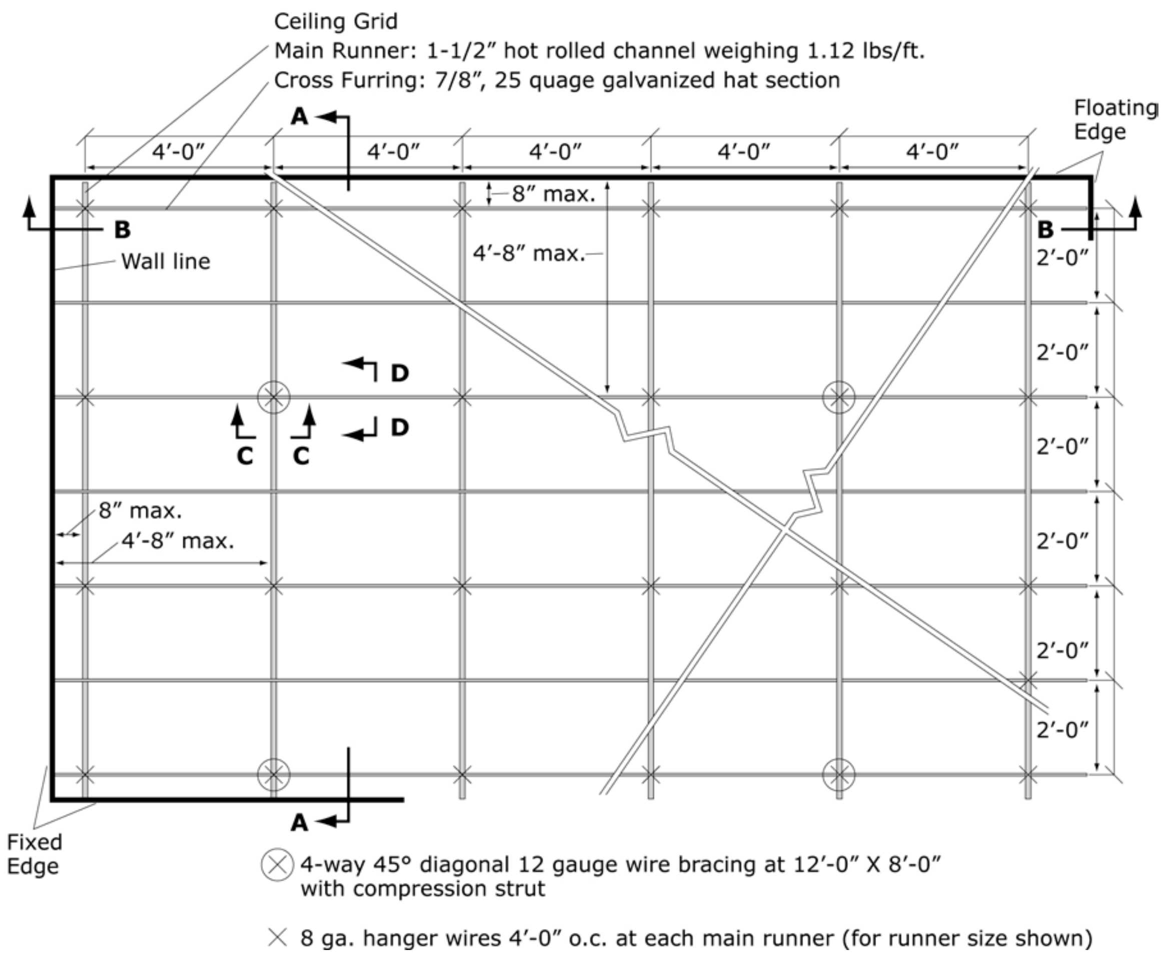


Figure 6.3.4.3-6 Diagrammatic view of suspended heavy ceiling grid and lateral bracing (PR).

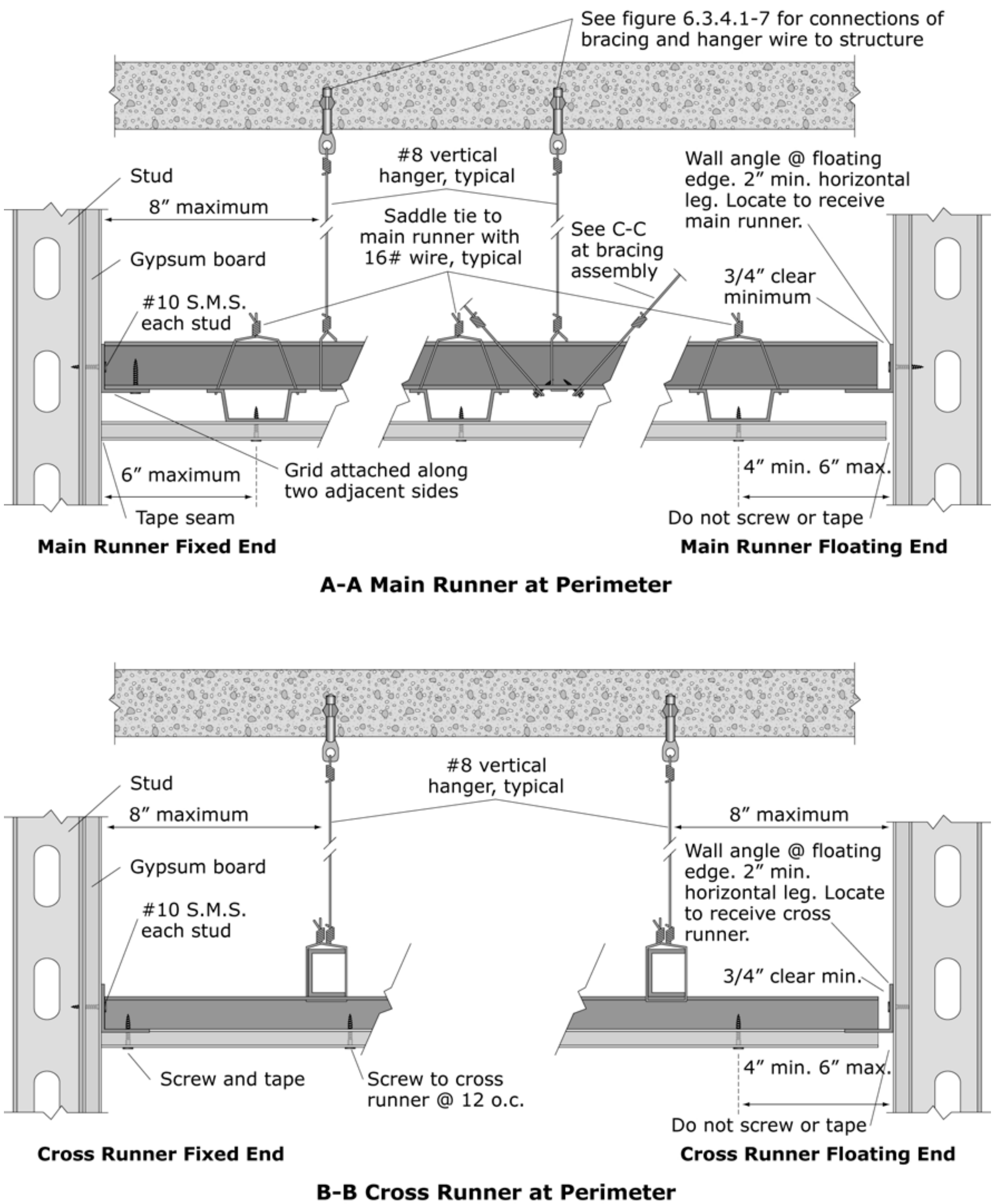
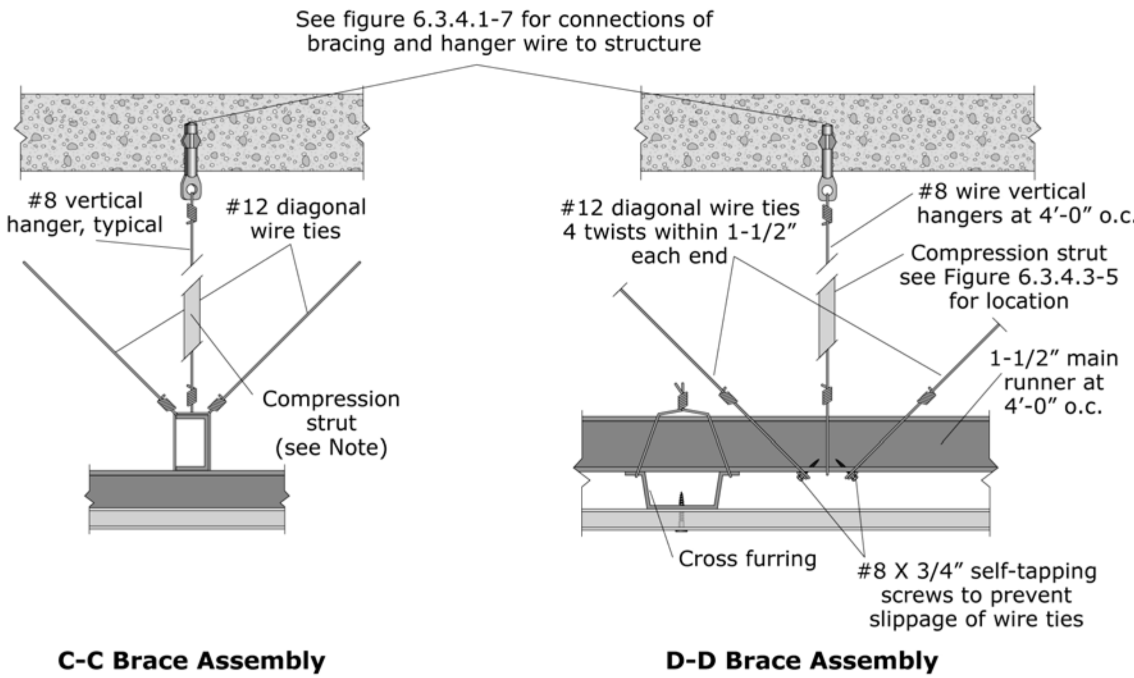


Figure 6.3.4.3-7 Perimeter details for suspended gypsum board ceiling (PR).



Note: Compression strut shall not replace hanger wire. Compresion strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4" min. expansion anchor to concrete. Size of strut is dependent on distance between ceiling and structure ($l/r \leq 200$). A 1" diameter conduit can be used for up to 6', a 1-5/8" X 1-1/4" metal stud can be used for up to 10'. See figure 6.3.4.1-6 for example of bracing assembly.

Figure 6.3.4.3-8 Details for lateral bracing assembly for suspended gypsum board ceiling (PR).